FRICTION LOSSES IN
PIPE FITTINGS AND VALVES

A THESIS

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by

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PIPE FITTINGS AND VALVES

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INTRODUCTION

Literature Survey

When a fluid flows through a pipe line consisting of straight pipe and fittings, there is a definite loss of pressure due to friction. This loss of head is often considerable and has been investigated many times.

Prof. F. E. Giesecke (1) was the first to investigate the friction loss caused by a fitting. He developed certain exponential formulae for the friction loss of head of water flowing through standard American pipes and fittings. Briefly summarized, the method of test was to allow water to flow from one tank to another, with and without the given pipes and fittings in the connecting line. In this manner, elbows of one-half inch to three inches nominal size pipe diameters were tested.

D. E. Foster (2) prepared a table tabulating friction losses for various type fittings ranging from one-half inch to twelve inches in diameter. Foster's work consisted of the rearrangement of a formula developed

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(1) Giesecke, F. E., "Formulas Deduced for Friction Loss in Water Pipes and Fittings", Engineering News Record, 79: 469: 1917.

(2) Foster, D. E., "Effect of Fittings on Flow of Fluids", Mechanical Engineering, 42: 616: 1920.

by Meier (3). Giesecke criticized Foster's values, saying that they were inaccurate and based on mistaken assumptions. He stated that Meier's factor of resistance "r", was not a constant for each type of fitting, but varied with the diameter, and that Foster assumed a constant value; thus Foster's values could not be applied to every diameter. Subsequent investigations by Giesecke confirmed the fact that Foster's calculated values were not checked by experimental evidence.

Until 1920 comparatively little reliable experimental work had been performed on the flow of very viscous liquids through commercial pipes and practically none had touched on the frictional resistance of fittings in viscous flow. Wilson, McAdams, and Seltzer (4) conducted many experiments on viscous flow through elbows and the determination of correction factors for the pressure drop around bends. Elbows of three sizes, one-inch, two-inch, and four-inch were tested. A manometer measured the pressure drop around the bends, which in each case consisted of two standard ninety degree elbows connected by a close nipple with straight pipe leading to the manometer connections which were forty diameters on each side of the elbows. The one-inch elbows were separated by a spacer one foot, eight and three-eighths inches in length, the two inch elbows by a spacer one foot, one inch in length and the four inch elbows by a spacer one and one-quarter inches in length.

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(3) Meier, K., The Mechanics of Heating and Ventilating.

(4) Wilson, McAdams, and Seltzer, "The Flow of Fluids Through Commercial Pipe Lines", Journal of Industrial and Engineering Chemistry, 14: 105-19: 1922.

The pressure drop through the straight pipe between manometer connections (excluding the two elbows) was calculated from the data secured at the same time on straight pipe alone, and the amount was subtracted from the total pressure drop around the bend. This value divided by two gave the pressure drop for one standard ninety degree elbow. The accuracy of these determinations of the pressure drop through elbows is doubtful due to the extremely short length of the spacer.

Two elbows separated by a spacer according to Corp and Hartwell (5) may be considered independently if the spacer is at least twenty diameters in length. When the spacer is shorter, however, the combined loss is less than the sum of the two elbows plus the friction of the spacer. It indicates that whenever two elbows are necessary in a pipe line, they should be installed as close together as possible. Corp and Hartwell also studied the losses in head for U, S, and twisted S pipe bends. This investigation disclosed that fifty per cent or more of the loss occasioned by an elbow occurs in the straight pipe below the fittings. Further they determined that losses due to the presence of bends in a pipe line are of two different origins; first, those due to eddying and disturbances of normal velocity distribution by virtue of the curvature or change of direction of flow; secondly, losses due to increased friction and interference because of diameter changes, differences of interior surfaces, unevenness of pipe connections, and changes in shape or form of passage.

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(5) Corp and Hartwell, "Experiments on Loss of Head in U, S, and Twisted S Bends", University of Wisconsin Engineering Experiment Station, Series Number 66.

Corp and Ruble (6) conducted experiments on the loss of head in valves and pipes of one-half inch to twelve inches in diameter. Valves, both globe and gate, were investigated for frictional losses at various openings. The effect of piezometer rings in a test line also was investigated. Their results indicated that the loss of head due to valves and other fittings occurs in part within the valve or fitting and in part as an added loss in the pipe line downstream where normal flow has been disturbed. Measurement ofthe loss of head where the downstream piezometer is attached too near the valve will give a loss in excess of that actually produced. From twenty to twenty-five pipe diameters beyondthe valve will probably give the best position for the downstream piezometer opening. According to their paper, globe valves offer from fifteen to forty times the resistance of gate valves for the same size pipe. This ratio increases with the increase in the size of valves. The length of straight pipe of the valve size which will produce the same loss of head varies from three-quarters of a foot to four feet for fully open gate valves and from twenty to thirty-five feet for fully open globe valves.

Additional work in the determination of loss of head in standard elbows and tees was conducted at Lafayette College by L. Perry (7). Standard one-inch, one and one-half inch, two and one-half inch, and three inch elbows and tees were used in the four different size pipe lines. The discharge was measured by permitting the water to flow into

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(6) Corp and Ruble, "Experiments on Loss of Head in Valves and Pipes of $\frac{1}{2}$ in. to 12 in. Diameter", Mechanical Engineering, 45: 250-51: 1923.

(7) Perry, L., "Tests of Loss of Head in Standard Elbows and Tees", Engineering News-Record, 92: 940: 1924.

a carefully calibrated tank and the velocity calculated. Overflows were used to maintain a constant head on the pipe containing the fitting, a constant head being necessary to maintain a constant velocity. The lost head was measured in each case by making piezometric connections to differential gages. Particular care was taken to have these connections just flush with the inside of the pipe. These connections were made four to seven inches above and six to eight inches below the fitting. The piezometric connections to the one-inch pipe were made directly to a tee screwed to a nipple of proper length and in turn screwed into the fitting. The additional loss of head due to the extra tees to which the piezometric tubes were connected was determined and proper allowances made. Due to the proximity of the piezometric connections to the test fitting, Perry's results do not appear to be very accurate.

Bruins, Othmer, James, and Berman (8) conducted an investigation to study the relation of the loss of head to velocity at several viscosities in various fittings. Only one-half inch streamline fittings were tested. The testing equipment consisted of ten test lines containing nine different fittings and one of straight pipe alone. The pressure drops were obtained for varying rates of flow. It was concluded that the pressure loss due to friction in fittings is dependent upon the velocity of flow. Due to the fact that the manometer connections were placed too close to the test fitting, it is highly probable that these results are inaccurate.

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(8) Bruins, Othmer, James, and Berman, "Friction of Fluids in Solder-Type Fittings", Transactions of the American Institute of Chemical Engineers, 36: 721-37: 1940.

Purpose

The object of the experimental work described herein was to fill in the gaps in the existing data on the flow of fluids in pipes of commercial size and roughness in the viscous flow region and in the critical region between viscous and turbulent flow; and to determine with reasonable accuracy correction factors for the pressure drop through fittings and valves.

This subject is very important for almost every engineer, operating man and designer alike, has frequent need to determine in advance the frictional pressure drop that is to be expected when some fluid with which he is concerned is to be forced or drawn through a pipe line containing various fittings and valves.

From the preceding survey it is noted that, in spite of the fact that a great deal of work has been conducted on this phase of fluid flow, there is a considerable variation in the results. Therefore this investigation was undertaken to check this previous work and establish the correct results.

Since straight pipe data is correlated with Reynolds number it seemed logical to present losses in fittings in this manner. Therefore, in design of piping installations the friction loss values in equivalent feet of various type fittings can be conveniently read from a graph once the Reynolds number is known.

A series of manometer connections was constructed on each side of the fitting in order to obtain an accurate measurement of the total loss caused by the fitting. Five feet of pipe separated the last manometer connections from any other fittings to prevent a disturbance in the test line which would render the results inaccurate. It was believed that a more reliable determination could be made in this way.

Theory

The friction loss of a fluid flowing through a pipe is but a special case of a general law of the resistance between a solid and fluid in relative motion. If a solid body of any desired shape be immersed in a fluid stream and the velocity of the fluid past the body is small in comparison with the velocity of sound, it has been found experimentally that the resisting force depends only on the roughness, size, and shape of the solid and on the velocity, density, and viscosity of the fluid. Through a consideration of the dimensions of these quantities it can be shown that:

$$F/A = pu^2/g \quad \phi' \cdot (Dup/\mu) \qquad (1)$$

where

F = the total resisting force.

A = the area of the body.

u = the velocity of the fluid past the body.

p = the density of the fluid.

D = the diameter.

μ = the viscosity of the fluid.

g = the acceleration of gravity.

ϕ' = some function whose precise form must be determined for each specific case.

In the particular case of a fluid flowing through a circular pipe of length L, the total force resisting the flow must equal the product of the area of contact between the fluid and the pipe wall, and the F/A of equation (1). The pressure drop will equal this product divided by the cross-sectional area of the pipe, since pressure is measured in force per unit area. (9)

$$\Delta P_f = F/A(4\ L\pi D/\pi D^2) = 4\ pu^2L/gD \cdot \phi'\ (Dup/\mu) \qquad (2)$$

or

$$\Delta P_f D/u^2 Lp = \phi\ (Dup/\mu) = \Delta H_f D/u^2 L \qquad (3)$$

where

ΔP_f = pressure drop due to friction in pounds per square foot.

F/A = resisting force in foot-pounds per square foot of contact area.

L = length of pipe in feet.

D = inside diameter of pipe in feet.

p = density of fluid in pounds per cubic foot.

u = average velocity of fluid in feet per second.

μ = viscosity of fluid in English units.

g = acceleration of gravity.

ΔH_f = loss in head due to friction in feet.

Certain general principles with regard to the flow of fluids are, of course, generally recognized. Thus it is well known that there are two general types of motion for fluids - usually called

(9) Badger and McCabe, Elements of Chemical Engineering, 1935, p. 35.

viscous and turbulent flow. Viscous flow is characteristic of low velocities, small pipes or very viscous liquids. In this form of motion, all of the particles move in lines parallel to the movement of the mass as a whole. In the case of every fluid, as the velocity is increased a point is eventually reached where a rapid transition takes place from viscous flow to an eddying, mixing type of motion known as turbulent flow. The transition velocity is called the critical velocity.

The Reynolds number (Dup/μ), indicated on the previous pages is of extreme importance in hydrodynamic discussions, because it correlates the various factors affecting flow. When the Reynolds number is less than 2100 in straight pipe, the flow is always viscous, and when above 4000, the flow is always turbulent. The range between these values is known as the critical region. The symbol for the Reynolds number used in this paper is "Re". This investigation was concerned with both the viscous and critical regions in determining the friction losses in pipe fittings and valves.

EQUIPMENT

The equipment used in the study of friction losses in standard one-inch galvanized iron pipe fittings consisted essentially of the following: a centrifugal pump, a constant head supply tank, a calibrated orifice for determining the rate of flow through the pipe and fittings, a pipe line containing the test fitting, a stretch of straight pipe, valves for controlling the rates of flow and a manometer for measuring the pressure drop across the lines and fittings. Mercury thermometers were provided to indicate the temperatures of the oil at entrance and exit.

Only standard one-inch galvanized iron pipe fittings and one-inch brass globe and gate valves were tested. The fittings tested were:

(1) a ninety degree elbow.

(2) a forty-five degree elbow.

(3) a tee, (oil entering branch).

(4) a tee, (oil leaving branch).

(5) a Y, (oil leaving branch).

(6) a cross, (oil leaving branch).

No data was found in the literature on fittings, (5) and (6).

The test line in which the fitting was tested consisted of manometer connections at one foot intervals for five feet on each side of the fitting being tested. The straight pipe was continued about five feet on each side of the manometer connections to eliminate all effect of bends. This portion of the test line is illustrated in Figure 2. By manipulating the proper needle valves, the friction loss between

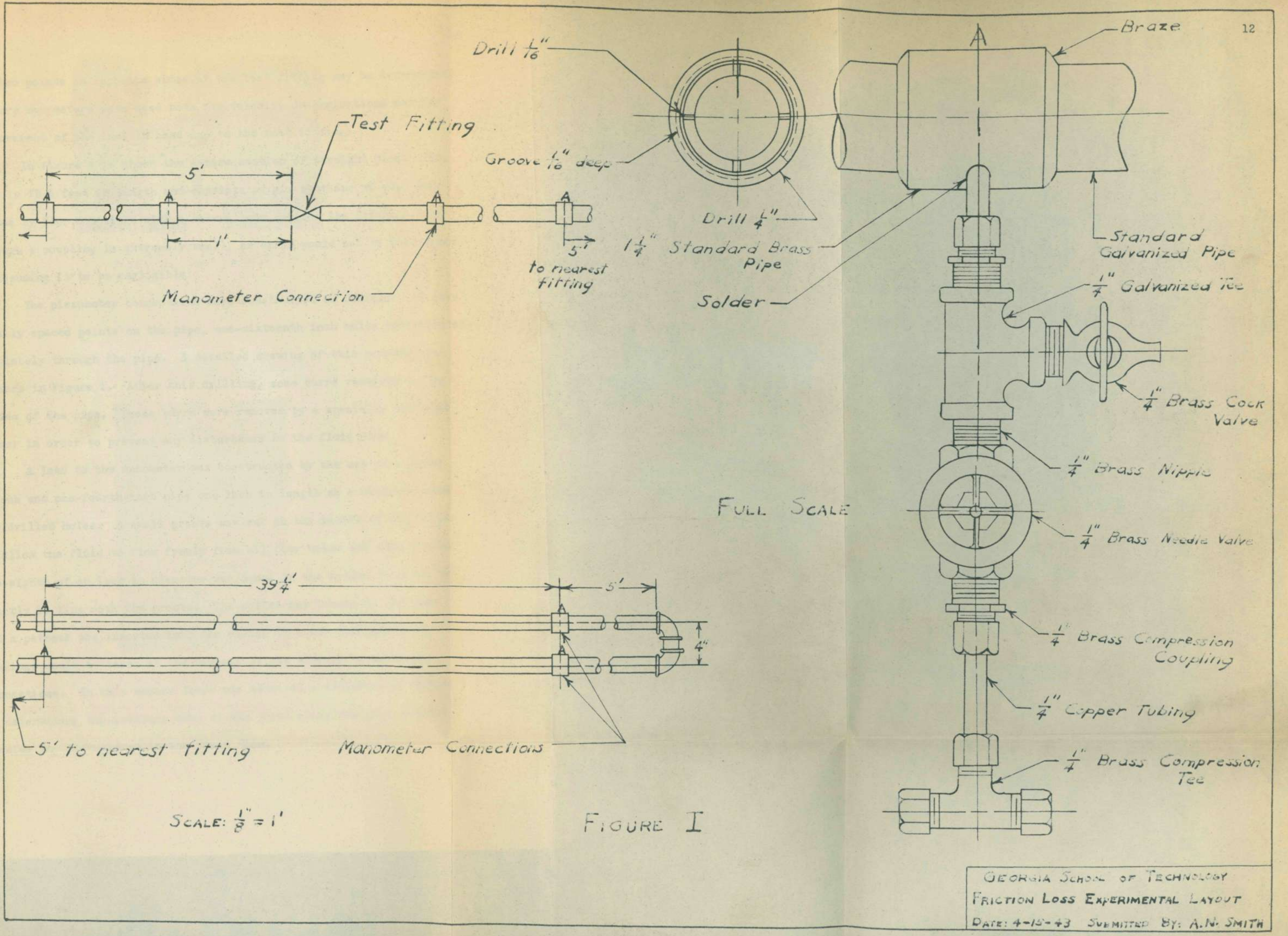
Test Fitting
5'
1'
5'
to nearest fitting
Manometer Connection
Drill 1/16"
Groove 1/16" deep
Drill 1/4"
1 1/4" Standard Brass Pipe
Solder
Braze
Standard Galvanized Pipe
1/4" Galvanized Tee
1/4" Brass Cock Valve
1/4" Brass Nipple
FULL SCALE
1/4" Brass Needle Valve
1/4" Brass Compression Coupling
1/4" Copper Tubing
1/4" Brass Compression Tee
39 1/4'
5'
4"
5' to nearest fitting
Manometer Connections
SCALE: 1/8" = 1'
GEORGIA SCHOOL OF TECHNOLOGY
FRICTION LOSS EXPERIMENTAL LAYOUT
DATE: 4-15-43 SUBMITTED BY: A.N. SMITH

FIGURE I

any two points on opposite sides of the test fitting may be determined. Mercury manometers were used both for velocity determinations and for measurement of the loss in head due to the test fitting.

In figure 4 is shown the entire section of straight pipe. This pipe is 78.5 feet in length and consists of six sections of pipe connected by four couplings with a return bend. Since the friction loss through a coupling is extremely small, an error would not be introduced by assuming it to be negligible.

The piezometer connections were constructed as follows: at four equally spaced points on the pipe, one-sixteenth inch holes were drilled completely through the pipe. A detailed drawing of this construction appears in Figure 1. After this drilling, some burrs remained on the inside of the pipe. These burrs were removed by a specially machined reamer in order to prevent any disturbance to the fluid flow.

A lead to the manometer was constructed by the use of a piece of one and one-fourth inch pipe one inch in length as a collar around the drilled holes. A small groove was cut on the inside of the collar to allow the fluid to flow freely from all four holes and then a hole one-eighth of an inch in diameter was bored in the collar so as to be exactly in line with the groove. The collar was brazed to the pipe and a petcock was inserted into the collar in order that manometer readings could be taken at the various points without breaking any connections. In this manner there was obtained a satisfactory method of determining the pressure drop at any point along the pipe without causing any disturbance in the fluid flow.

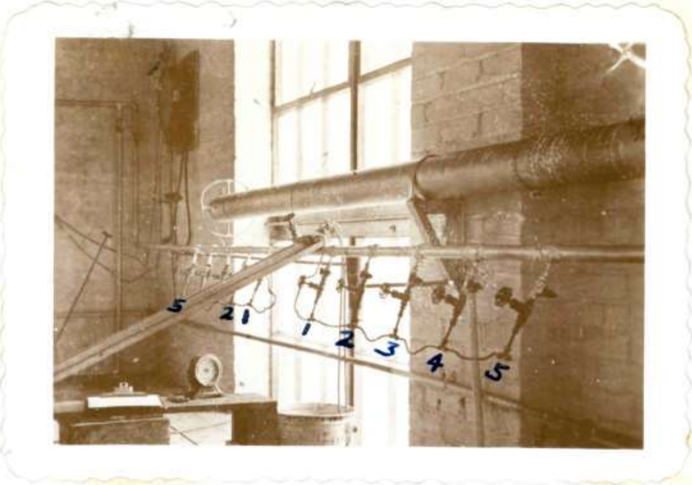

Figure 2. Test Section

Figure 3. Centrifugal Pump and Tank

Figure 4. Straight Pipe Section

PROCEDURE

A series of runs was made at various oil temperatures varying from low to high rates of flow and vice versa. The oil was pumped from the constant head tank through the lines until the entire system was brought to a state of equilibrium. The temperature of the oil was recorded and the velocity obtained from the reading of the manometer attached to the orifice. The cock valves at the manometer and pipe were then opened to flush out the air. All valves were then closed.

Referring to Figure 2, the pair of needle valves marked 1-1 were opened and the manometer reading recorded. It is obvious that this value represents the friction loss encountered in the fitting plus two feet of straight pipe. The losses across 2-2, 3-3, 4-4, and 5-5 were obtained in the same manner. These losses were determined at various velocities.

The results obtained were converted into friction loss in feet of oil and plotted against the feet of pipe. The resulting straight line was extrapolated past the zero point until it intersected the negative abscissa. The point of intersection gave the equivalent length of the fitting in feet directly. The zero point or intersection of the line with the ordinate gave the friction loss in feet of oil caused by the fitting. This method is depicted in the appendix. These valves determined by the intersection of the negative abscissa were plotted against Reynolds number. These results were checked by converting the feet of oil into equivalent lengths through the use of the straight pipe data on Figure 5. The graphical and calculated results are included in the tabulated data. The most convenient method of expressing the frictional resistance due to an elbow of given size is in terms of the equivalent length of straight pipe which will give the same resistance to the flow of a given fluid. It is customary to express the equivalent length in terms of pipe diameters rather than feet so that the figure will be substantially the same for all sizes of pipes.

TABLE I

Straight Pipe

D=1.049"   L=78.5'

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Friction Loss $\frac{\Delta H_f D}{u^2 L}$
96	0.88	46	0.0269
98	0.88	49	0.0268
100	0.88	53	0.0267
102	0.88	56	0.0267
104	0.96	66	0.0225
106	0.99	72	0.0213
110	1.19	98	0.0148
113	1.23	114	0.0138
116	1.32	135	0.0118
120	1.45	166	0.00962
123	1.53	196	0.00844
126	1.62	228	0.00734
130	1.76	276	0.00615
133	1.84	320	0.00545
136	1.92	359	0.00484
140	2.04	422	0.00409
143	2.15	482	0.00352
146	2.22	540	0.00320
150	2.36	634	0.00269
153	2.45	705	0.00242
156	2.52	780	0.00221
160	2.60	873	0.00198
163	2.71	980	0.00173
166	2.78	1,060	0.00159
168	2.85	1,115	0.00147
172	3.00	1,260	0.00140
177	3.14	1,460	0.00134
188	3.21	1,840	0.00127

TABLE II

45° Elbow

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
95	1.60	81	0.10	0.10	0.05
98	1.70	95	0.14	0.15	0.08
102	1.79	114	0.21	0.20	0.10
104	1.84	127	0.22	0.21	0.10
106	1.92	142	0.25	0.22	0.10
110	2.15	180	0.38	0.29	0.13
115	2.30	227	0.41	0.33	0.15
120	2.42	278	0.50	0.40	0.16
124	2.51	331	0.61	0.49	0.18
127	2.57	375	0.70	0.61	0.21
130	2.60	407	0.76	0.67	0.22
132	2.65	442	0.82	0.75	0.24
135	2.74	500	0.91	0.87	0.25
138	2.82	560	0.94	0.90	0.25
140	2.89	595	0.97	0.93	0.25
143	2.94	659	1.12	1.07	0.27
146	3.00	729	1.18	1.11	0.27
150	3.12	835	1.22	1.25	0.27
153	3.20	920	1.40	1.34	0.28
156	3.28	1,015	1.42	1.46	0.28
160	3.32	1,150	1.43	1.47	0.28
163	3.36	1,215	1.48	1.47	0.28
166	3.44	1,295	1.49	1.47	0.28
172	3.50	1,470	1.49	1.48	0.28
175	3.54	1,580	1.49	1.48	0.28
178	3.56	1,700	1.49	1.48	0.28
182	3.58	1,820	1.49	1.50	0.28
185	3.59	1,905	1.49	1.51	0.28
188	3.62	2,020	1.49	1.51	0.28
191	3.63	2,140	1.49	1.51	0.28
194	3.64	2,200	1.49	1.52	0.28
198	3.66	2,450	1.49	1.54	0.28
200	3.68	2,540	1.49	1.55	0.28
203	3.70	2,670	1.49	1.55	0.28
206	3.71	2,830	1.49	1.55	0.28
208	3.72	2,920	1.49	1.55	0.28
210	3.73	3,060	1.49	1.55	0.28

TABLE III

Globe Valve

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
92	1.27	57	1.48	1.25	0.60
95	1.47	74	1.48	1.26	0.60
98	1.58	89	1.54	1.33	0.61
102	1.72	110	1.60	1.36	0.64
105	1.81	128	1.73	1.51	0.70
108	1.93	150	2.08	1.76	0.79
112	2.08	185	2.50	2.20	0.94
115	2.15	212	2.90	2.62	1.05
120	2.30	263	3.52	3.09	1.19
124	2.42	319	3.70	3.60	1.30
127	2.50	365	4.00	3.95	1.34
130	2.53	400	4.40	4.40	1.40
133	2.62	456	5.70	5.48	1.60
136	2.68	500	6.28	6.00	1.66
140	2.76	570	6.65	6.70	1.72
143	2.86	642	7.60	7.60	1.83
146	2.90	705	8.06	8.12	1.86
150	2.99	802	8.40	8.99	1.90
153	3.06	880	8.70	9.80	1.90
156	3.10	960	9.00	10.61	1.95
160	3.17	1,064	9.32	10.69	1.95
163	3.24	1,175	9.32	10.69	1.95
166	3.26	1,230	9.32	10.69	1.95
172	3.34	1,410	9.41	10.90	1.95
175	3.36	1,502	9.41	11.00	1.95
178	3.40	1,616	9.41	11.00	1.95
180	3.41	1,670	9.41	11.02	1.95
183	3.44	1,770	9.41	11.02	1.95
187	3.46	1,900	9.41	11.08	1.95
190	3.48	2,038	9.41	11.40	1.95
193	3.48	2,143	9.41	11.50	1.95
197	3.54	2,320	9.41	11.29	1.95
200	3.56	2,450	9.41	11.38	1.95
205	3.60	2,680	9.41	11.40	1.95

TABLE IV

90^{o} Elbow

Oil Temp. ^{o}F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
90	1.42	61	0.17	0.14	0.07
98	1.76	99	0.20	0.16	0.08
100	1.81	110	0.20	0.19	0.10
106	2.06	152	0.30	0.25	0.13
110	2.21	182	0.33	0.32	0.16
113	2.31	214	0.44	0.39	0.18
116	2.40	247	0.55	0.51	0.23
120	2.51	288	0.80	0.70	0.30
123	2.61	334	0.91	0.82	0.33
126	2.67	374	1.01	0.92	0.35
130	2.74	434	1.08	1.08	0.36
136	2.92	547	1.30	1.25	0.38
140	3.02	625	1.48	1.48	0.41
143	3.07	688	1.61	1.59	0.43
146	3.18	769	1.78	1.78	0.45
150	3.27	875	1.88	1.92	0.45
154	3.34	980	2.04	2.12	0.46
157	3.39	1,079	2.12	2.27	0.46
160	3.43	1,150	2.20	2.30	0.46
163	3.49	1,262	2.30	2.39	0.47
166	3.52	1,322	2.41	2.40	0.47
170	3.58	1,450	2.41	2.40	0.47
173	3.60	1,540	2.41	2.40	0.47
176	3.62	1,650	2.41	2.40	0.47
181	3.67	1,825	2.41	2.43	0.47
184	3.68	1,920	2.41	2.44	0.47
187	3.71	2,040	2.41	2.56	0.47
190	3.71	2,170	2.50	2.59	0.49
193	3.72	2,300	2.50	2.55	0.49
196	3.76	2,420	2.50	2.59	0.49
200	3.76	2,590	2.50	2.60	0.49
203	3.77	2,730	2.50	2.60	0.49
206	3.79	2,880	2.50	2.60	0.49
208	3.80	2,950	2.50	2.60	0.49
210	3.81	3,070	2.50	2.60	0.49

TABLE V

Tee (Oil entering branch)

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
90	1.31	56	0.20	0.19	0.10
92	1.45	65	0.30	0.22	0.12
96	1.71	90	0.37	0.28	0.15
102	1.98	127	0.40	0.28	0.15
106	2.11	156	0.49	0.39	0.20
110	2.22	185	0.69	0.53	0.26
113	2.32	217	0.71	0.80	0.32
116	2.42	252	0.91	0.80	0.35
120	2.52	292	1.00	0.88	0.37
125	2.66	366	1.20	1.05	0.40
128	2.72	405	1.40	1.26	0.45
133	2.84	495	1.51	1.47	0.46
136	2.92	547	1.70	1.60	0.49
139	3.00	617	1.90	1.69	0.53
142	3.08	676	2.10	2.00	0.55
145	3.15	746	2.41	2.28	0.60
148	3.22	824	2.80	2.66	0.65
153	3.32	955	2.91	3.07	0.65
156	3.38	1,048	3.10	3.16	0.65
159	3.42	1,128	3.20	3.34	0.65
162	3.43	1,205	3.24	3.35	0.65
165	3.48	1,300	3.38	3.35	0.65
168	3.54	1,385	3.40	3.35	0.65
171	3.57	1,470	3.40	3.35	0.65
174	3.60	1,580	3.47	3.35	0.65
177	3.62	1,680	3.47	3.35	0.65
180	3.64	1,790	3.47	3.35	0.65
183	3.66	1,882	3.47	3.35	0.65
186	3.69	1,988	3.47	3.35	0.65
189	3.72	2,130	3.47	3.35	0.65
192	3.73	2,260	3.60	3.39	0.65
195	3.76	2,380	3.60	3.39	0.65
196	3.77	2,430	3.60	3.39	0.65
198	3.78	2,525	3.60	3.41	0.65
200	3.79	2,610	3.60	3.41	0.65
202	3.80	2,720	3.60	3.41	0.65
204	3.82	2,785	3.60	3.40	0.65
206	3.83	2,918	3.60	3.40	0.65
208	3.83	3,010	3.60	3.40	0.65
210	3.84	3,082	3.60	3.40	0.65

TABLE VI

Gate Valve

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
86	0.95	35	0.075	0.076	0.022
88	1.08	43	0.085	0.083	0.030
90	1.14	49	0.09	0.084	0.034
94	1.22	59	0.10	0.094	0.040
97	1.34	72	0.11	0.10	0.045
100	1.62	98	0.12	0.11	0.050
103	1.67	113	0.12	0.12	0.050
106	1.80	133	0.17	0.15	0.065
110	2.00	165	0.20	0.17	0.075
113	2.12	196	0.25	0.19	0.080
116	2.18	225	0.29	0.25	0.100
120	2.24	256	0.31	0.27	0.103
124	2.32	306	0.37	0.30	0.103
127	2.43	354	0.40	0.32	0.105
130	2.48	392	0.41	0.36	0.110
133	2.55	444	0.45	0.39	0.110
136	2.62	485	0.46	0.41	0.110
140	2.73	565	0.48	0.44	0.110
143	2.82	632	0.51	0.46	0.110
146	2.86	695	0.52	0.48	0.110
150	2.94	790	0.57	0.51	0.110
153	3.02	868	0.59	0.55	0.110
156	3.06	948	0.62	0.59	0.110
160	3.15	1,060	0.64	0.62	0.110
163	3.22	1,170	0.67	0.63	0.115
166	3.24	1,220	0.67	0.64	0.116
170	3.30	1,335	0.67	0.64	0.116
173	3.35	1,440	0.67	0.64	0.116
176	3.40	1,550	0.67	0.64	0.116
180	3.45	1,695	0.67	0.64	0.116
183	3.46	1,785	0.67	0.64	0.116
186	3.54	1,910	0.67	0.64	0.116
190	3.55	2,085	0.67	0.64	0.116
193	3.56	2,200	0.67	0.67	0.116
197	3.58	2,350	0.67	0.67	0.116
200	3.60	2,480	0.67	0.67	0.116
205	3.62	2,700	0.67	0.68	0.116
210	3.68	2,960	0.67	0.66	0.116
215	3.72	3,260	0.67	0.66	0.116

TABLE VII

Tee (Oil leaving branch)

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
88	1.30	51	0.11	0.10	0.05
90	1.38	59	0.20	0.15	0.08
96	1.62	85	0.30	0.25	0.12
99	1.69	99	0.39	0.31	0.15
105	1.92	138	0.48	0.34	0.19
108	2.04	150	0.48	0.38	0.19
110	2.15	161	0.52	0.39	0.20
112	2.22	200	0.65	0.55	0.25
116	2.36	246	0.75	0.62	0.27
118	2.42	266	0.90	0.76	0.31
121	2.52	306	0.90	0.78	0.32
125	2.63	357	1.20	1.00	0.38
128	2.72	408	1.30	1.12	0.40
132	2.80	466	1.40	1.23	0.40
135	2.93	534	1.49	1.35	0.42
139	3.04	625	1.60	1.51	0.42
142	3.12	685	1.65	1.54	0.43
145	3.18	753	1.81	1.70	0.43
150	3.28	880	1.90	1.98	0.43
154	3.35	980	2.02	2.12	0.44
156	3.39	1,058	2.16	2.14	0.44
160	3.48	1,168	2.20	2.19	0.45
165	3.54	1,322	2.30	2.28	0.45
170	3.60	1,452	2.40	2.34	0.46
173	3.62	1,550	2.40	2.34	0.46
175	3.64	1,630	2.40	2.36	0.46
180	3.68	1,808	2.40	2.36	0.46
183	3.70	1,905	2.40	2.34	0.46
185	3.73	1,980	2.40	2.34	0.46
186	3.73	2,005	2.40	2.36	0.46
187	3.74	2,060	2.40	2.36	0.46
191	3.76	2,240	2.50	2.40	0.47
197	3.77	2,500	2.50	2.40	0.47
200	3.82	2,630	2.50	2.44	0.47
202	3.84	2,750	2.50	2.44	0.47
205	3.86	2,878	2.50	2.44	0.47
207	3.86	2,970	2.50	2.44	0.47
208	3.88	3,040	2.50	2.43	0.47

TABLE VIII

Cross

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
92	1.36	62	0.20	0.21	0.10
94	1.39	68	0.26	0.22	0.10
97	1.54	83	0.30	0.29	0.13
100	1.71	104	0.40	0.32	0.15
103	1.84	124	0.49	0.39	0.19
106	2.00	146	0.59	0.43	0.21
110	2.13	176	0.65	0.47	0.22
113	2.26	209	0.70	0.55	0.25
116	2.35	242	0.77	0.61	0.25
120	2.44	280	0.88	0.69	0.28
123	2.53	324	0.91	0.77	0.30
126	2.60	364	1.01	0.87	0.32
130	2.69	425	1.10	0.96	0.32
133	2.78	483	1.19	1.04	0.32
136	2.86	530	1.39	1.23	0.37
140	2.94	608	1.50	1.40	0.38
143	3.02	677	1.61	1.49	0.40
146	3.06	744	1.72	1.64	0.42
150	3.15	846	2.03	1.99	0.45
153	3.22	925	2.17	2.14	0.45
156	3.24	1,000	2.40	2.48	0.46
160	3.32	1,113	2.50	2.51	0.46
163	3.38	1,222	2.50	2.51	0.46
166	3.42	1,285	2.55	2.51	0.46
170	3.46	1,395	2.69	2.58	0.47
173	3.48	1,488	2.69	2.58	0.47
176	3.50	1,594	2.69	2.58	0.47
180	3.53	1,730	2.69	2.60	0.47
183	3.55	1,850	2.69	2.60	0.47
186	3.60	1,940	2.69	2.60	0.47
190	3.62	2,120	2.72	2.60	0.47
193	3.63	2,240	2.72	2.60	0.47
196	3.64	2,342	2.72	2.60	0.47
202	3.64	2,660	2.72	2.61	0.47

TABLE IX

Y

Oil Temp. °F	Velocity ft/sec	Reynolds No. Re	Equivalent Graph.	Length Calc.	Head Loss ΔH_f
92	1.49	67	0.08	0.08	0.04
95	1.63	82	0.12	0.10	0.05
98	1.72	96	0.19	0.15	0.08
100	1.74	108	0.20	0.16	0.08
104	1.89	131	0.29	0.22	0.11
107	2.00	151	0.36	0.27	0.13
110	2.12	177	0.41	0.32	0.15
115	2.29	226	0.44	0.37	0.16
120	2.43	279	0.55	0.45	0.18
124	2.54	334	0.60	0.50	0.19
127	2.62	385	0.67	0.57	0.20
130	2.67	423	0.73	0.67	0.22
132	2.70	450	0.77	0.70	0.22
135	2.82	515	0.90	0.83	0.24
140	2.92	604	1.00	0.93	0.25
143	3.00	671	1.07	0.99	0.26
146	3.06	742	1.13	1.08	0.27
150	3.14	840	1.22	1.26	0.28
153	3.22	925	1.38	1.38	0.29
156	3.28	1,015	1.49	1.55	0.30
160	3.34	1,120	1.50	1.60	0.30
163	3.38	1,221	1.52	1.60	0.30
166	3.43	1,280	1.56	1.60	0.30
170	3.48	1,410	1.64	1.64	0.31
173	3.52	1,510	1.64	1.64	0.31
176	3.54	1,615	1.64	1.65	0.31
180	3.56	1,745	1.64	1.65	0.31
185	3.60	1,910	1.64	1.65	0.31
188	3.62	2,020	1.64	1.65	0.31
192	3.64	2,210	1.64	1.68	0.31
195	3.66	2,320	1.64	1.69	0.31
200	3.70	2,547	1.64	1.69	0.31
202	3.70	2,650	1.64	1.71	0.31
204	3.72	2,720	1.64	1.71	0.31
210	3.76	3,000	1.64	1.70	0.31

Comparison with Published Values

Table X

Fittings	Test Values (Diameters) Re = 100	Re = 2500	Published Values (Diameters) Turbulent Ermenc (11)	Flow Perry (10)
Forty-five degree elbows.	1.9	18	15	19
Ninety degree elbows.	1.9	30	32	35
Tee (oil leaving branch).	3.5	29	60	46
Tee (oil entering branch).	3.2	39	90	46
Gate valve (full-open).	1.2	8	7	9
Globe valve (full-open).	15.5	132	300	240
Cross (off-run).	3.6	30	--	46
Y (off-run).	1.9	20	--	34

(10) Perry, J. H., loc. cit.

(11) Ermenc, E.,"Friction Losses in Pipe Fittings and Valves", Master's Thesis, Georgia School of Technology.

DISCUSSION

Curves

The curves obtained are very similar in shape for all the fittings. In the range of Reynolds numbers between 1100 and 3000, the equivalent length is practically constant.

The forty-five degree elbow and Y curves are very similar and the losses incurred in these fittings in the viscous flow region are approximately the same. The losses in the ninety degree elbow, cross and tee where the fluid leaves the branch are approximately the same over the total range of Reynolds numbers. In the case of the tee where the fluid enters the branch, the loss is considerably higher. The loss through the gate valve was extremely small, whereas the loss through the globe valve was considerably higher than any of the fittings tested. It is readily seen from the graphs that the equivalent length is a function of Reynolds number.

The manometer readings constituted the main source of error. This was especially true in the determination of losses in the globe valve where a variation in the manometer readings made an average reading necessary.

Suggestions for further work and improvement.

Tests should be made on different sized pipe fittings and the friction losses correlated with the diameter. Additional fittings should also be tested.

The investigation should extend farther into the critical region of flow in order to obtain the losses in fittings within that region also.

CONCLUSIONS

1. In the viscous flow region the friction losses incurred in the ninety degree standard radius elbow, cross and tee in which the fluid leaves the branch are approximately the same.

2. The equivalent length increases with Reynolds number as a straight line function. It increases rather rapidly in the viscous flow region, but remains approximately constant in lower range of the critical region.

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APPENDIX

Sample Calculations

$$\Delta P = \Delta H(d_1-d_2)$$

$$\Delta H_r = \Delta H_i(S.G._1-S.G._2)$$

45° Elbow

Run	Connection Number	Manometer Left	Manometer Right	ΔH_i	ΔH_r
	1-1	6.31	5.39	0.92	0.775
	2-2	6.66	5.04	1.62	1.36
I	3-3	6.98	4.72	2.26	1.90
	4-4	7.31	4.39	2.92	2.46
	5-5	7.64	4.06	3.58	3.01

u = 2.60 ft./sec.
T = 130°F

Run	Connection Number	Manometer Left	Manometer Right	ΔH_i	ΔH_r
	1-1	6.28	5.42	0.86	0.72
	2-2	6.88	5.12	1.46	1.22
II	3-3	6.89	4.81	2.08	1.75
	4-4	7.16	4.54	2.62	2.20
	5-5	7.45	4.25	3.20	2.69

u = 2.89 ft./sec.
T = 140°F

Manometer used --- mercury-oil.

Inclination of manometer --- $\sin \Theta = 0.728$

$$\Delta H_r = \Delta H_i \ (S.G._1-S.\ G._2)\sin \Theta$$

$$\Delta H_r = \frac{0.92}{12}\ (13.6-0.915)0.728$$

$$\Delta H_r = 0.775 \text{ feet of oil}$$

The above data was plotted on the accompanying graph, from which the following results are obtained:

	I	II
Equivalent Length (ft.)	0.76	0.87
ΔH_f (feet of oil)	0.22	0.25

All results were obtained by similar methods.

Sample Calculations (cont.)

The equivalent length values were calculated from H_f using the values obtained from Figure 5 on straight pipe.

$$\text{Reynolds Number} = \frac{D\,u\,p}{\mu} = Re$$

$D = 1.04"$
$u = 2.60$ ft./sec.
$p = 56.0$ lb./cu.ft.
$\mu = 46.2$ centipoises

$$Re = \frac{1.04 \times 2.60 \times 56}{12 \times 46.2 \times 0.000672}$$

Run I $\quad Re = 407.0$

$$\frac{\Delta P_f D}{p u^2 L} = 0.0043 \qquad \text{Figure 5}$$

$$\frac{\Delta P}{L} = 0.0043 \times 2.60 \times 2.60 \times 56 = 18.73$$

$$\frac{p \Delta H_f}{\frac{\Delta P}{L}} = \frac{\text{Pressure}}{\text{fitting}} \times \frac{\text{ft. pipe}}{\text{pressure}} = \frac{\text{ft. pipe}}{\text{fitting}}$$

$$L = \frac{56.0 \times 0.22}{18.73} = 0.67 \text{ ft.}$$

Calculation Method

L = 0.67 feet of one-inch galvanized pipe

Graphical Method

L = 0.76 feet of one-inch galvanized pipe

		Graph	Calculated
Run II	Equivalent Length	0.97	0.93

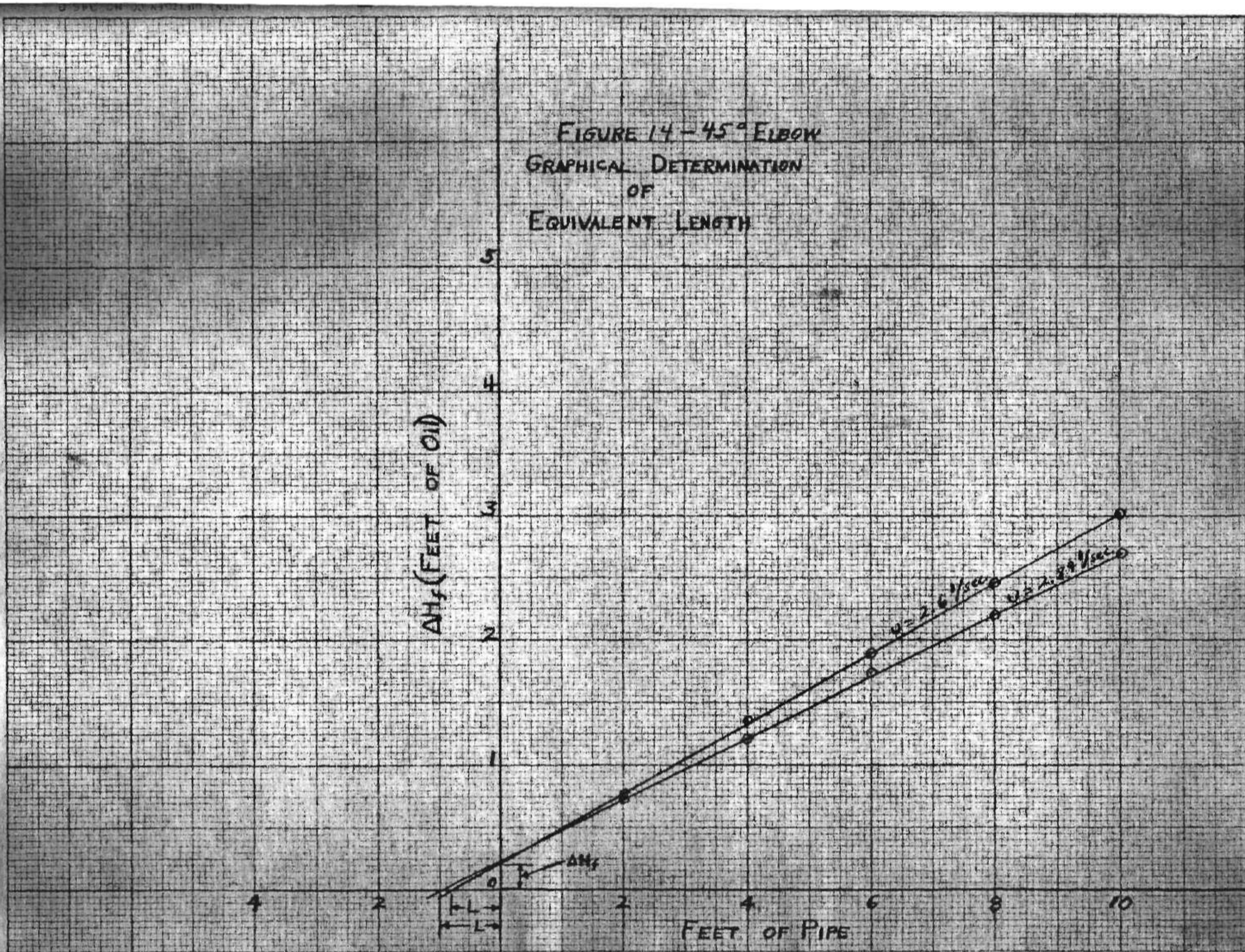
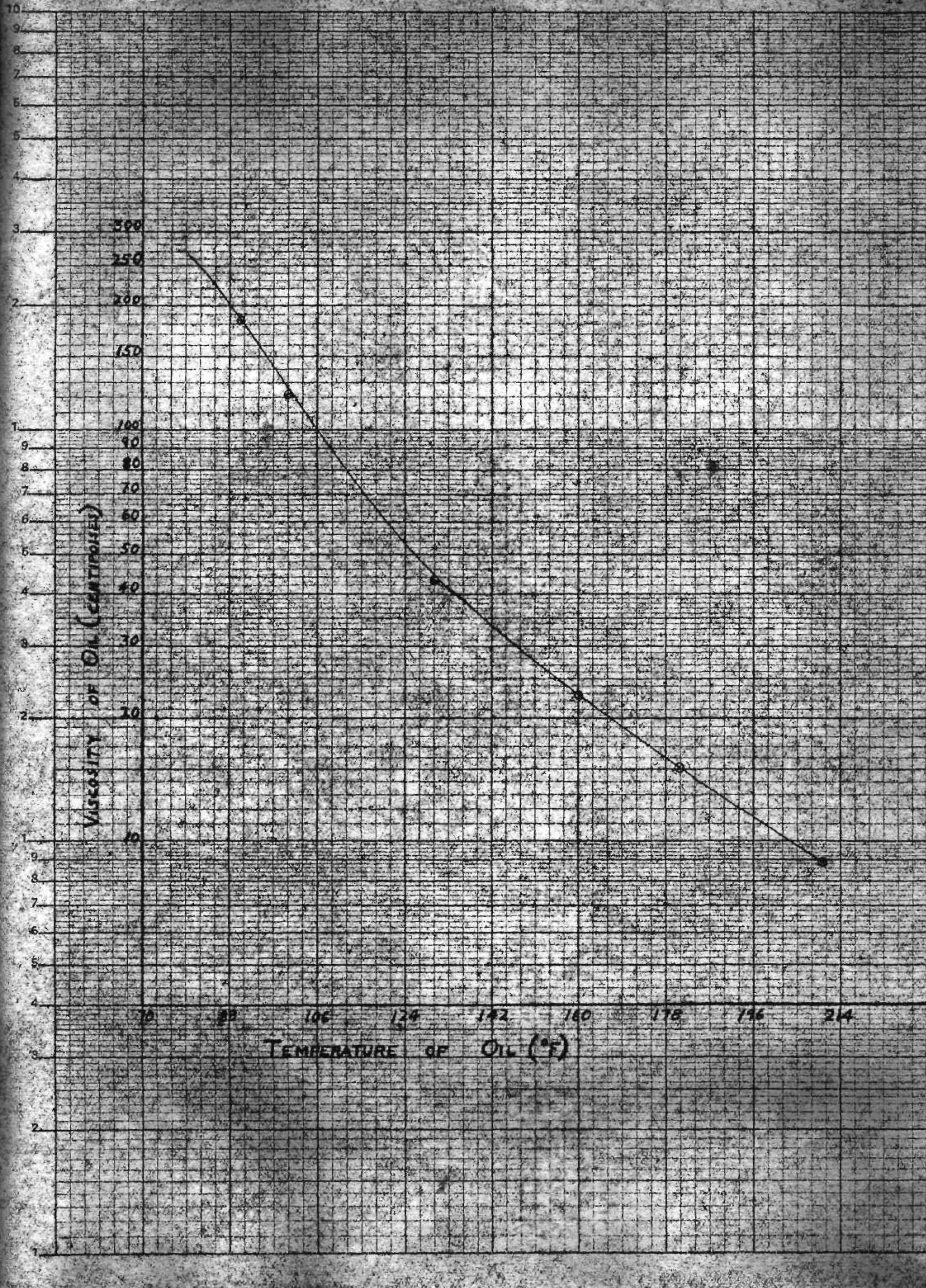


FIGURE 14 – 45° ELBOW
GRAPHICAL DETERMINATION
OF
EQUIVALENT LENGTH


300
250
200
150
100
90
80
70
60
50
40
30
20
10
VISCOSITY OF OIL (CENTIPOISES)
70
88
106
124
142
160
178
196
214
TEMPERATURE OF OIL (°F)